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Radioactive Waste Dilution in the Clinch River Eastern Tennessee

By P. H. CARRIGAN, Jr.

TRANSPORT OF RADIONUCLIDES BY STREAMS

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Prepared in cooperation with the U.S. Atomic Energy Commission and the Oak Ridge National Laboratory

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By P. H. CARRIGAN, JR.

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Abstract

A convenient, direct measure of simple volumetric dilution of low-level radioactive liquid wastes released from the Oak Ridge National Laboratory by waters of the Clinch River has been defined. This measure of dilution is called the dilution factor. The dilution factor is the ratio of flow in the Clinch River to flow of the radioactive liquid waste stream (Whiteoak Creek) for concurrent periods of time.

Dilution characteristics of the Clinch River and Whiteoak Creek have been described by means of several types of statistical analyses: central tendencies, extremes, cumulative frequency distribution, seasonal trends, and magnitude-duration-frequency curves of minimum dilution factors.

In order to apply results of these statistical analyses, complete and steady mixing of the waters of the Clinch River and Whiteoak Creek must be assumed. Exploratory diffusion tests indicate that complete mixing in the cross section has occurred within a reasonable distance downstream from the mouth of Whiteoak Creek.

Flows in the Clinch River in the vicinity of Whiteoak Creek have been affected considerably by releases from Norris Lake for peak-demand hydroelectric power. Other exploratory tests indicate that the effects of the variation in flow of the Clinch River were almost completely evened out through processes of turbulent diffusion.

INTRODUCTION

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This report describes a contribution of the U.S. Geological Survey to the Clinch River Study. The Clinch River Study was a multiagency effort to evaluate the past, present, and future use of the Clinch River for disposal of low-level radioactive liquid waste from the Oak Ridge National Laboratory, operated by Union Carbide Corp. for the U.S. Atomic Energy Commission, in eastern Tennessee (Morton, 1961, 1962, 1963). The agencies that participated in the study are: Oak Ridge National Laboratory; Tennessee Game and Fish Commission; Tennessee State Department of Public Health, Stream Pollution Control Board; Tennessee Valley Authority; U.S. Atomic Energy Commission; U.S. Geological Survey; and U.S. Public Health Service.

When the study was begun in 1960, the Clinch River Study Steering Committee, an advisory group composed of representatives of each of the participating agencies (Morton, 1963, p. 1), established the following objectives: (1) To determine the fate of radioactive materials currently being discharged to the Clinch River, (2) to determine and understand the mechanisms of dispersion of radionuclides released to the river, (3) to evaluate the direct and indirect hazards of current disposal practices in the river, (4) to evaluate the overall usefulness of the river for radioactive waste disposal purposes, and (5) to provide appropriate conclusions regarding long-term monitoring procedures.

Work described in this report was part of a cooperative program with the Health Physics Division, Oak Ridge National Laboratory; the Oak Ridge Operations Office, U.S. Atomic Energy Commission; and the Division of Reactor Development and Technology, U.S. Atomic Energy Commission.

The release of low-level radioactive liquid waste to the basin of Whiteoak Creek, which drains the Oak Ridge National Laboratory (ORNL) area, was begun soon after establishment of ORNL in 1943 for the processing of radioactive materials. Radioactive liquids have entered Whiteoak Creek as a result of direct releases of processed waste water from ORNL, seepage from liquid-waste holdup pits, and drainage from solid-waste disposal trenches (Browder, 1959).

Throughout most of ORNL's history, the waters of Whiteoak Creek have been impounded in Whiteoak Lake by Whiteoak Dam, which is located 0.6 mile upstream from the mouth of the creek. The lake was created as a holdup facility for the radioactive waste carried in the creek water. Radioactive waste waters in Whiteoak Creek flow into the Clinch River at a point 3.3 miles downstream from the ORNL area. The diluted wastes in the Clinch River flow into the Tennessee River 20.8 miles downstream from the entry of Whiteoak Creek.

The continuous release of radioactivity to the Clinch River during nearly 20 years of ORNL operations has provided a unique opportunity for studying the effects of such releases on the river and the effects of the physical, chemical, hydrologic, and biological characteristics of the river on the fate of the radioactivity.

Dilution of radioactive waters, which are released to the Clinch River through Whiteoak Dam (fig. 1, inset), by flow in the river has been an integral part of waste water treatment at ORNL. Concentrations of low-level radioactivity in these releases have been greater than desirable levels in the creek. Through dilution afforded by the river, concentrations have been reduced to very acceptable levels in the river (see Morgan, 1959a, p. 447).

Various estimates of average dilution afforded by the river have been made; estimated dilution has ranged from 450 to 1,000 times the average discharge in Whiteoak Creek (for example, see Morton, 1962, p. 106, and Feige and others, 1960, p. 25). unc. Variations in estimates stem from using different bases of flow comparisons: different periods of record, different streamflow measuring sites.

Other statistical measures of available dilution such as the median and the frequency of occurrence of minimums had not been estimated until this work was undertaken.

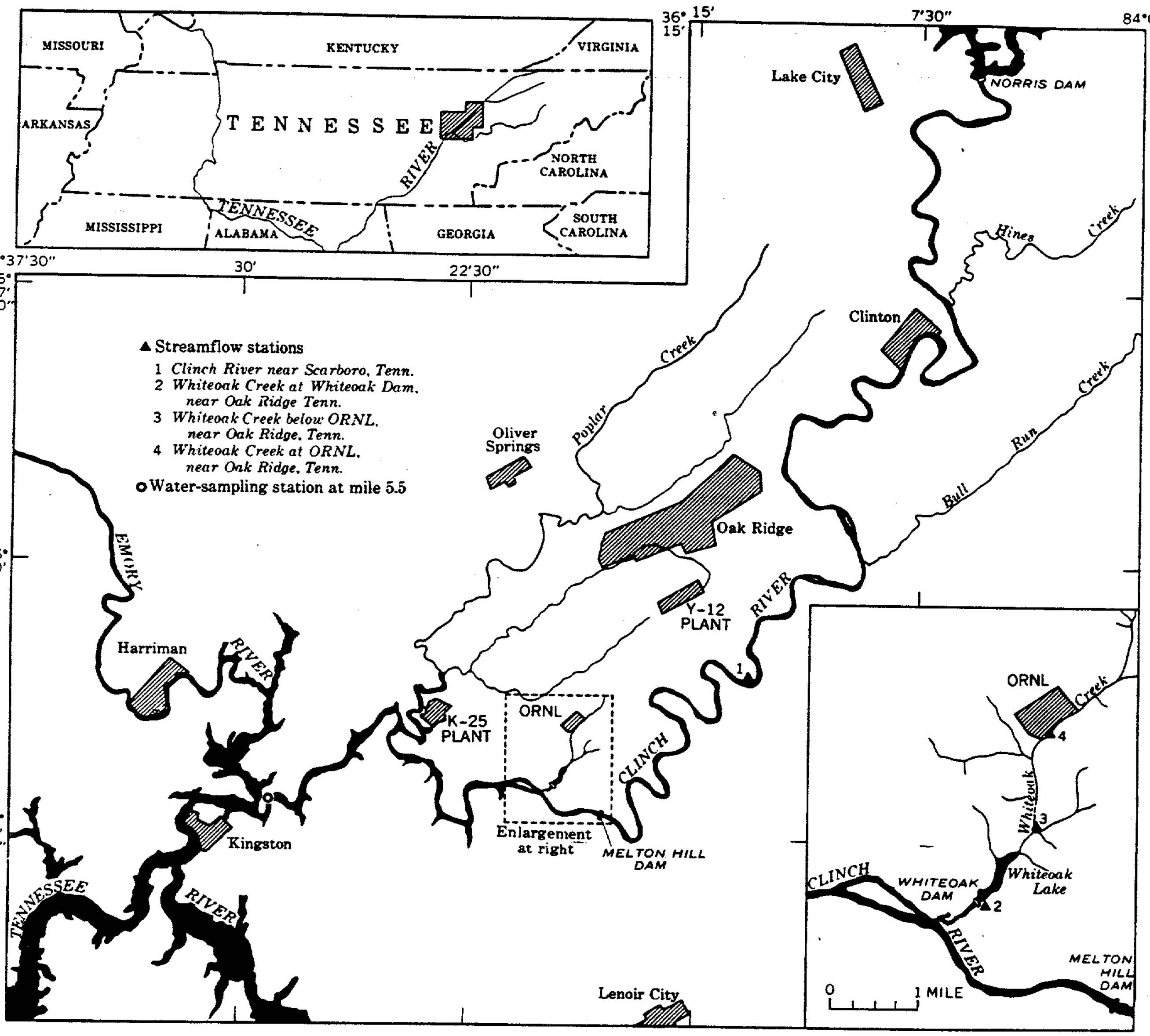

FIGURE 1.—Lower Clinch River basin from Norris Lake to river mouth.

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Three of the principal radionuclides, strontium-90, ruthenium-106, and cobalt-60, released continuously into the river, are transported downstream into the Tennessee River without substantial uptake by bottom sediments or biota. (See Churchill and others, 1965; Carrigan and Pickering, 1967, p. 63.) These radionuclides are moving in the water as solutes or as finely divided, nonsettleable, particulate matter. Hence, reduction of concentration of the three radionuclides, once complete mixing of waters from Whiteoak Creek with those of the Clinch River takes place rapidly, occurs within 4 to 6 miles downstream from the creek mouth (Morton, 1963, p. 70).

Dilution of releases from Whiteoak Creek by waters of the Clinch River is not constant, variation in dilution being a function of variations in flows of both streams. Because of the complexity in relationship in flows of the two streams, description of the influence of dilution on the fate of radioactive materials is best attacked through statistical analyses.

Various types of statistical analyses are presented in this report to characterize the dilution afforded by the river: central tendency, extremes, cumulative frequency distribution, seasonal trends, and magnitude-duration-frequency curves.

Techniques of statistical analyses employed are those commonly utilized in statistical descriptions of variations in streamflow. Extension of these techniques to consideration of simultaneous variation in flows of two streams is new and unusual and demonstrates another useful interpretation of streamflow data.

Consistency in analysis is maintained by using a selected base period of record and by limiting streamflow data to that obtained at one streamflow observation station on Whiteoak Creek and to one on the Clinch River.

ACKNOWLEDGMENTS

The efforts of Shirley A. Wilson and Harold Erickson of the U.S. Geological Survey in completing the initial computations of the mass of data leading to the statistical analyses of dilution factors are gratefully acknowledged. The help of personnel of the Waste Disposal Research Section, Health Physics Division, ORNL, under the direction of E. G. Struxness, in conducting the turbulent diffusion tests in August 1961, including radiochemical analyses, is also acknowledged. Records of discharge in the Clinch River near Scarboro, Tenn., were obtained through the cooperation of the Tennessee Valley Authority. Figures 1 and 5 were prepared in the Graphic Arts Department, ORNL.

STREAMFLOW CHARACTERISTICS OF WHITEOAK CREEK AND THE CLINCH RIVER

Variations in flow of Whiteoak Creek reflect, almost completely, variations in natural runoff in its basin. Flows through Whiteoak Dam normally are uncontrolled, the lake serving only for emergency storage needs.

Average flow in Whiteoak Creek at Whiteoak Dam, near Oak Ridge, Tenn. (fig. 1, sta. 2), for the period of record, 1953–55, 1960–63, is 13.5 cfs (cubic feet per second); drainage area at this station is 6.01 square miles (U.S. Geological Survey, unpub. data, 1963, p. 71).

Accretions to the flow in the creek (imported water) from various waste streams in ORNL are 28 percent of the average flow (from data furnished by ORNL and streamflow records).

Flow in the lower Clinch River is highly regulated in contrast to the virtually natural flow in Whiteoak Creek. For purposes of this report, only effects of regulation by Norris Lake require description.

Norris Dam, at mile 79.8, is a multipurpose structure used in the generation of peak-demand electric power and for flood control. Once or twice daily, releases are commonly made from Norris Lake to meet peak-power demands. Often on weekends either no release or diminished releases are made because of decreased power demands. During storm periods, floodflows are attenuated by temporary storage in Norris Lake. As soon as the flood threat has abated in the Tennessee Valley, sustained high releases (15,000–20,000 cfs) are made from the lake for several days.

The mouth of Whiteoak Creek is at mile 20.8 on the Clinch River. The streamflow gaging station in operation furthest downstream on the Clinch River prior to 1962 was at mile 39.0 near Scarboro, Tenn. (fig. 1, sta. 1); the station was 18.2 miles upstream from the mouth of the creek. Average flow for the period of record at this station, 1936–62, was 4,612

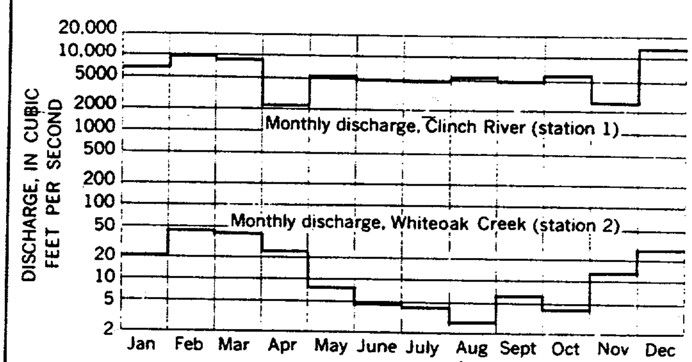

FIGURE 2.—Comparison of flows in Whiteoak Creek and the Clinch River during 1951. Distances between the two curves indicate variations in the river's dilution of radioactive releases from the creek.

cfs. Drainage area of the Clinch River at this site is 3,300 square miles (U.S. Geological Survey, unpub. data, 1962, p. 66).

DILUTION FACTOR

In figure 2, variations in monthly flows during 1951 are shown for the Clinch River near Scarboro, Tenn. (fig. 1, sta. 1), and for Whiteoak Creek at Whiteoak Dam, near Oak Ridge, Tenn. (fig. 1, inset, sta. 2). Linear differences between the curves for the two streams, which is the difference in logarithms of flows, are a direct measure of the relative dilution. Changes in the distances between curves, in figure 2, indicate that an appreciable variation in dilution occurs during the year.

One method of describing variations in dilution factors would be to establish, first, the relationship between discharges of the Clinch River and Whiteoak Creek by methods of correlation analyses. After the relationship between discharges for a selected period of record had been established, variation in dilution factor could be completely described by variation in discharge of one stream.

A correlation of the logarithms of concurrent flows in Whiteoak Creek and in Clinch River was attempted, but as can be surmised from study of figure 2 the results were unsatisfactory. The index of correlation was 0.363 (Ezekiel and Fox, 1959, p. 131), and the standard error of estimate was ±0.182 log units (equivalent to +52, —34 percent) (Ezekiel and Fox, 1959, p. 65).

Because of lack of good correlation between discharges of the two streams, some other method of describing the relationship of discharges is needed.

Another measure which can be used to describe the dilution of releases afforded by the Clinch River is the ratio of flows in the two streams, called the dilution factor. The dilution factor is defined as the ratio of flow in Clinch River near Scarboro, Tenn. (mile 39.0), to that in Whiteoak Creek at Whiteoak Dam, near Oak Ridge, Tenn. for concurrent periods of time.

COMPUTATION OF DILUTION FACTORS

SELECTED PERIOD OF RECORD

The base period of record selected for statistical studies of dilution factors is from October 1, 1950, to September 30, 1960, 10 water years (1951–60). This period was selected for two reasons: (1) during the period, cumulative departure of precipitation from average precipitation for the long-term meteorological station at Clinton, Tenn. (fig. 1), was near zero and (2) no streamflow records for Whiteoak Creek basin were available for the period prior to 1950.

Records of discharge in the Clinch River at the gaging station near Scarboro, Tenn. are available for the entire base period. Records of discharge in Whiteoak Creek at the gaging station at Whiteoak Dam, near Oak Ridge, Tenn., are available for July 10, 1953, to October 14, 1956, and for August 1 to September 30, 1960.

EXTENSION OF DISCHARGE RECORDS FOR WHITEOAK CREEK

Discharges in Whiteoak Creek at Whiteoak Dam were estimated for the periods of missing record on the basis of records for the gaging station Whiteoak Creek below ORNL, near Oak Ridge, Tenn. (fig. 1, inset, sta. 3). The latter station was operated from June 1950 to July 1953 and from July 1955 to September 1960.

Statistical correlation is a means by which short-term records for a station such as that on Whiteoak Creek at Whiteoak Dam are adjusted to represent a long-term record (Searcy, 1960, p. 68). Virtually no concurrent periods of record were available to develop a suitable relation between discharges for the two stations, Whiteoak Creek at Whiteoak Dam and Whiteoak Creek below ORNL, through correlation analysis. However, discharge records at a third station, Whiteoak Creek at ORNL, near Oak Ridge, Tenn. (fig. 1, sta. 4), were available for the period June 1, 1950, to July 14, 1955. Periods of records available for streamflow stations in Whiteoak Creek basin are shown in figure 3.

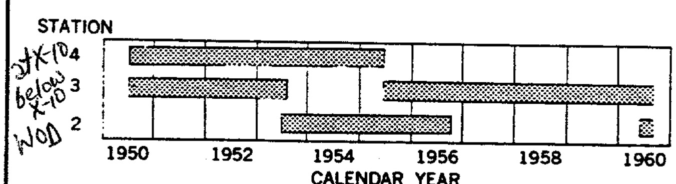

FIGURE 3.—Periods of records available for streamflow stations in Whiteoak Creek basin. (See fig. 1.)

Availability of discharge records for the station Whiteoak Creek at ORNL made possible definition of a relationship between discharges for two pairs of stations on Whiteoak Creek: (1) for the stations at ORNL and at Whiteoak Dam and (2) for the stations at ORNL and below ORNL. Statistical correlations, using graphical techniques described by Searcy (1960), were used to develop the two relationships. Indices of correlation were 0.995 and 0.993, respectively, and standard errors of estimate were 0.0624 log units (equivalent to +15, —13 percent) and 0.034 log units (equivalent to +8, —5 percent), respectively.

The relationships in discharge for the above two pairs of stations were used to develop through cross-plotting technique the relation between discharges for the stations below ORNL and at Whiteoak Dam. Although the index of correlation for the latter pair of stations cannot be computed, it can be safely implied that the coefficient is about 98 percent and that the standard error of estimate is about +18, —15 percent.

The relationship used to estimate daily discharges in Whiteoak Creek at Whiteoak Dam for the missing periods of record is curve 1 in figure 4.

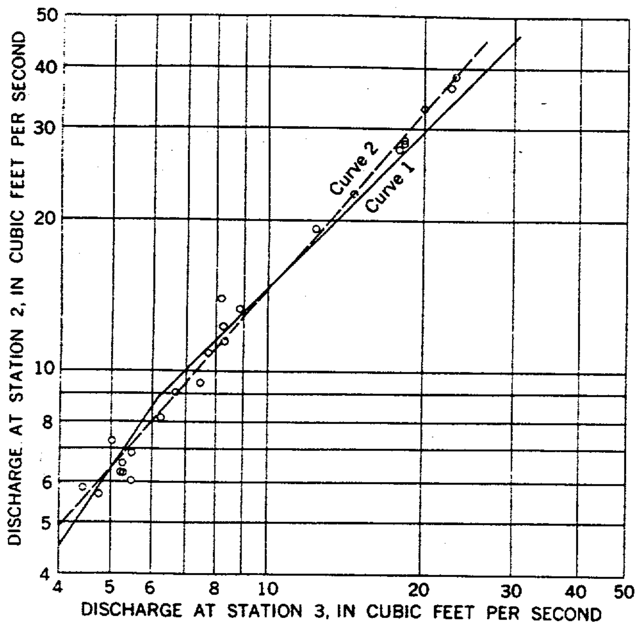

FIGURE 4.—Relationships between monthly discharges for two streamflow stations in Whiteoak Creek basin: Whiteoak Creek at Whiteoak Dam (sta. 2) and Whiteoak Creek below ORNL (sta. 3).

A primary requisite for correlation, that homogeneity in the hydrologic environment exist (H. C. Riggs, written commun., 1962), seems to be partially satisfied because the two stations are in close proximity—at either end of Whiteoak Lake. Another requirement to satisfy completely the criteria for homogeneity is the development of correlations for each month in the year, rather than a single correlation that includes all monthly data. Some divergence from this latter requirement would seem permissible. The period of concurrent records for any of the stations in Whiteoak Creek basin was certainly too short to permit development of monthly correlations.

Study of methods of correlation analyses in the Water Resources Division, U.S. Geological Survey, subsequent to the time the daily dilution factors for this report were computed, has indicated that algebraic methods of correlation are preferable to graphical techniques (Walter Hoffman, written commun., 1962). When discharge records for the 1963 water year were available, postdating analytical record leading to this report, statistical correlation was made of monthly discharges for Whiteoak Creek below ORNL and Whiteoak Creek at Whiteoak Dam using algebraic methods described by Ezekiel and Fox (1959). The data for this correlation and the resultant regression curve (curve 2) are superposed on the original regression curve (curve 1) in figure 4. For the algebraically determined curve, the index of correlation is 0.993 and the standard error of estimate is ±0.0321 log units (equivalent to +8, —7 percent). The standard error of estimate for curve 1 in figure 4 is 0.0595 log units (+15, —13 percent), and the index of correlation is 0.976 (determined by techniques described by Arkin and Colton, 1950, p. 76, 80).

RESULTS OF STATISTICAL ANALYSES

MINIMUM, MEAN, AND MAXIMUM DAILY DILUTION FACTORS

The mean daily dilution factor for the 10-year base period, 1951–60, was 670. This factor was computed as the sum of the daily dilution factors divided by the number of days in the 10-year period. For the same period the mean dilution factor, computed as the ratios of average discharges for the base period, was 390. For shorter periods of record, mean dilution factor, based on the ratio of average discharges for the shorter period, had been about 450. The mean dilution factor, based on the ratio of daily flows, is greater because the sum of quotients is greater than the quotient of the sums.

Minimum daily dilution factor during the base period was 5.1, occurring on February 6, 1955. Maximum daily dilution factor was 4,330, occurring on January 4, 1955.

PROBABILITY OF EQUALING OR EXCEEDING SPECIFIED DILUTION FACTORS

The cumulative-frequency curve showing probability of equaling or exceeding specified dilution factors is called a dilution-factor-duration curve. This curve is the integral of the frequency distribution curve for the daily dilution factors, with integration proceeding from the highest to the lowest daily dilution factor.

Probability of equaling or exceeding any specified daily dilution, within the range of experience, may be determined from the duration curve shown in figure 5. For example, daily dilution factors of 1,400 and 87 are equaled or exceeded 10 and 90 percent of the time, respectively. Median daily dilution factor for the base period was 570.

Methods used to define the dilution-factor-duration curve (fig. 5) are the same as those described by Searcy (1959) to define flow-duration curves.

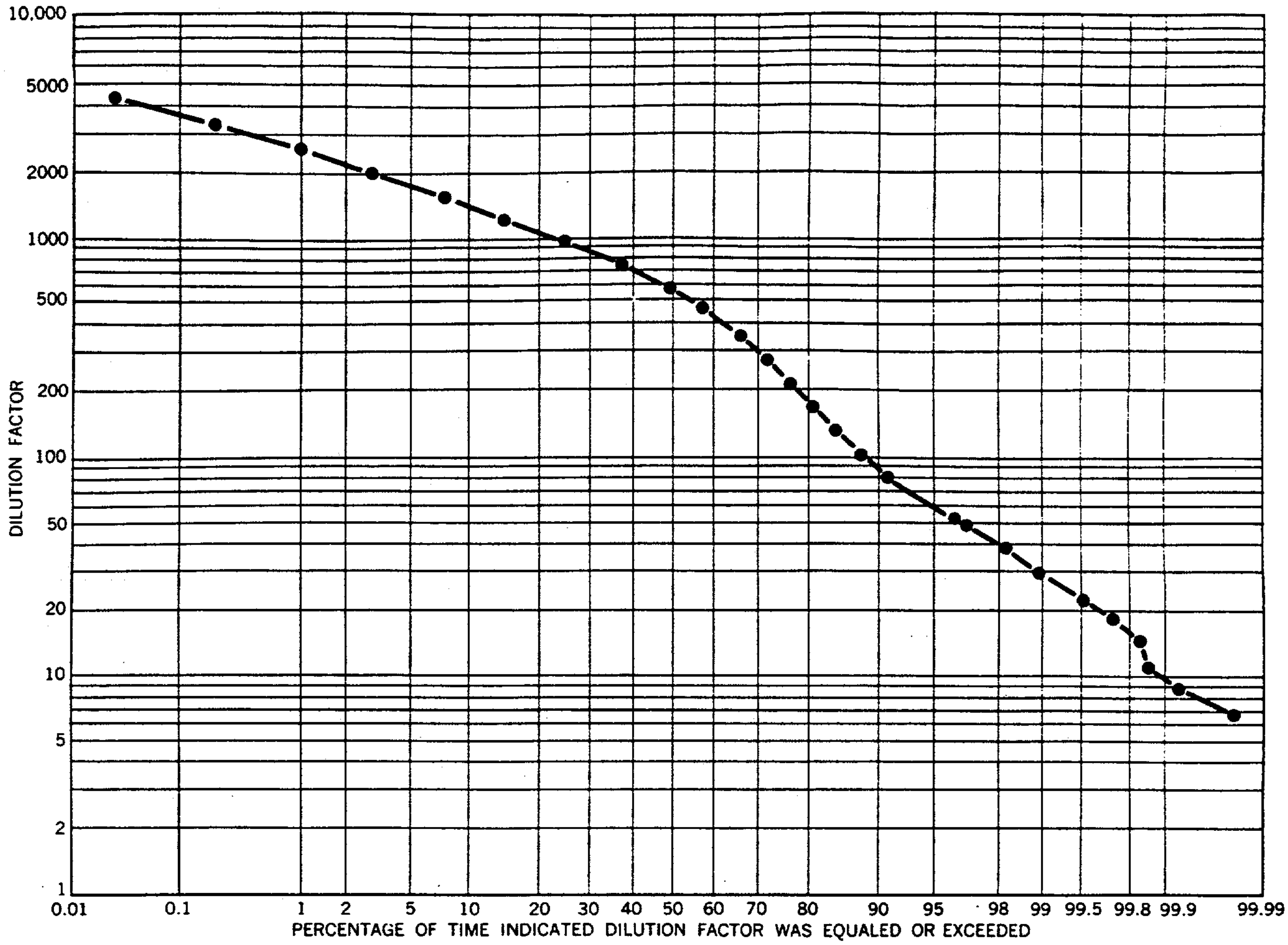

FIGURE 5.—Duration curve of daily dilution factors for the period 1951–60.

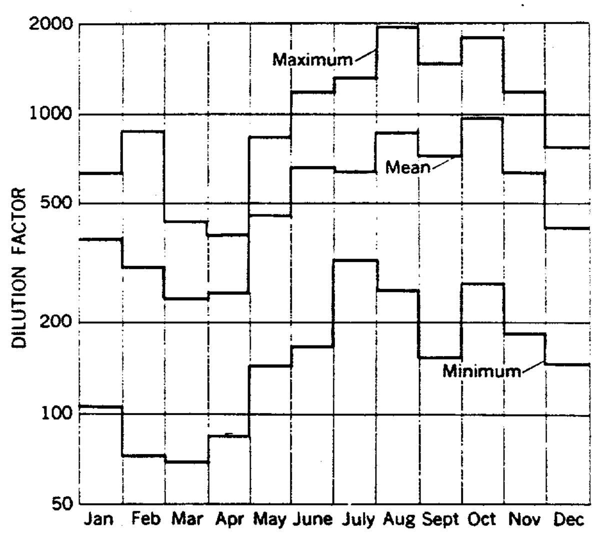

FIGURE 6.—Seasonal variations in dilution factors showing maximum, mean, and minimum monthly factors during the period 1951–60.

SEASONAL VARIATIONS IN DILUTION

As shown in figure 6, mean monthly dilution factors vary during the year in a somewhat sinusoidal manner. Magnitudes of monthly factors are less than the mean daily dilution factor in 6 successive months, December through May. Lowest monthly dilution factors occur in March; the highest may occur in August or October.

Variation in minimum or maximum monthly dilution factors follow the same general seasonal pattern as that for mean monthly dilution factors. Minimum mean monthly dilution factors have been found to be 320 or less in all months of the year.

Dilution factors, computed for use in figure 6, are ratios of concurrent mean monthly flows in the Clinch River to those in Whiteoak Creek during the 10-year base period.

The individual influence on the dilution factor of flow in the Clinch River and of flow in Whiteoak Creek was statistically tested. Results of the test did not indicate that variation in creek flow, or in river flow, exerted a dominant influence on variation in the dilution factors.

FREQUENCY STUDIES OF MINIMUM DILUTION FACTORS

Results of frequency studies of minimum dilution factors which occur annually for durations of 1, 3, 7, 15, 30, 60, and 90 days are shown in figure 7.

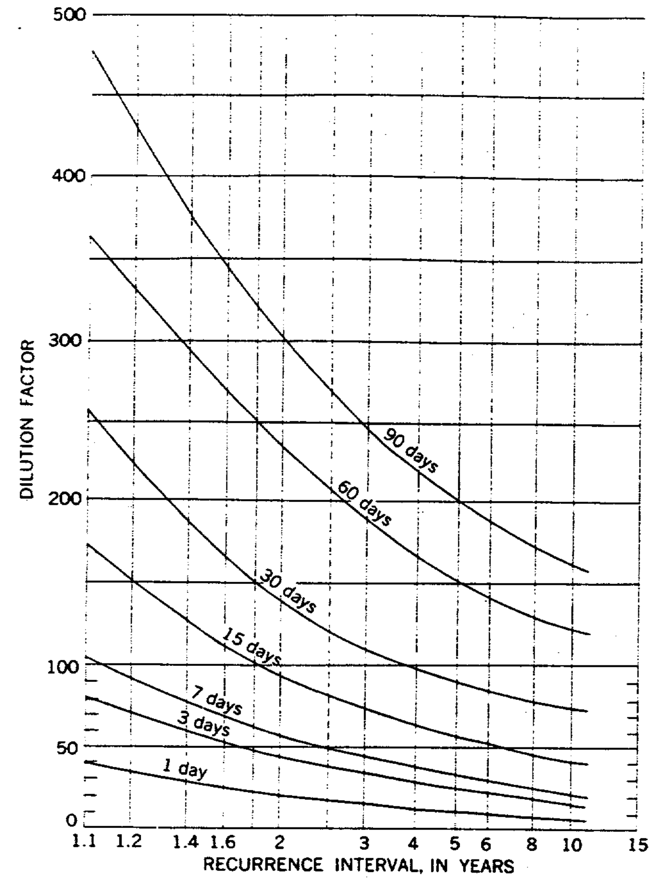

FIGURE 7.—Annual minimum dilution factor frequency curves for durations from 1 to 90 days during the period 1951-60.

The number of occurrences of an event of given magnitude in a given period of time is expressed in terms of a recurrence interval. In this context the recurrence interval (fig. 7, abscissa) is the average interval of time within which the dilution factor will, at least once, be equal to or less than a given magnitude. The recurrence interval also can be considered as the reciprocal of the probability of a dilution factor of given magnitude occurring in any year; for instance, the dilution factor with recurrence interval of 2 years is one that has a 50-percent chance of occurring in any year; the factor with 5-year recurrence interval has a 20-percent chance of occurring in each year; the factor with a 10-year recurrence interval has a 10-percent chance of occurring in each year.

In the following table, minimum dilution factors of specified duration are listed for recurrence intervals of 2 and 10 years.

Duration (*days*)	*Recurrence intervals*	
	2 years	*10 years*
1	20	6
3	44	20
7	58	27
15	94	41
30	140	75
60	234	123
90	302	163

Methods to define the magnitude-duration-frequency curves are those described by Furness (1960, p. 5-19) in his work concerned with low-flow frequency curves.

EFFECTS OF DIFFUSION IN THE CLINCH RIVER ON DILUTION

Waters draining from Whiteoak Creek do not immediately mix with waters of the Clinch River. Through the process of turbulent diffusion, waters of the two streams do mix—vertically, laterally, and longitudinally—as they move downstream. Unless the mixing process occurring in the river is completed within a reasonable distance downstream from the mouth of Whiteoak Creek application of information on dilution factors would not be useful to other phases of the Clinch River Study.

In exploratory steady-flow diffusion tests, the author and B. J. Frederick, U.S. Geological Survey, found, as had F. L. Parker, ORNL (in Morgan, 1959b, p. 9), that vertical and lateral mixing of Whiteoak Creek waters with the Clinch River waters was virtually complete within a distance of 4 to 6 miles downstream from the mouth of Whiteoak Creek for flows of 6,000 to 20,000 cfs. The region of the river channel in which cross-sectional mixing is first complete is upstream from any point of major water use and upstream from water-sampling stations established for studying the fate of the waterborne radioactive wastes. (See Churchill and others, 1965.)

For purposes of exploring effects of diffusion on

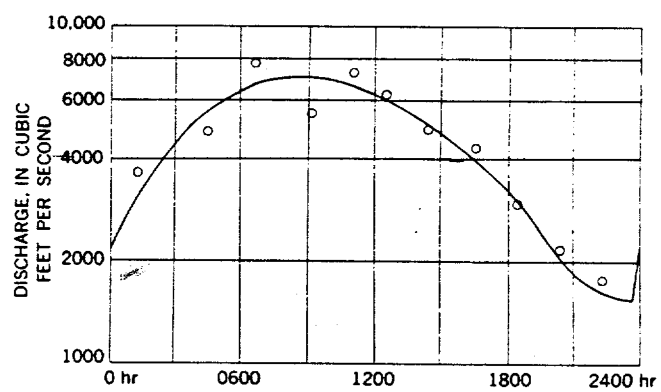

FIGURE 8.—The typical variation in flow of the Clinch River during a day in the vicinity of Whiteoak Creek, due to power releases from Norris Lake during Aug. 14-19, 1961. (Same variation in flow observed at mile 5.5 except for timelag of 40 min.)

dilution, release of water from Whiteoak Creek into the Clinch River may be considered to vary so slowly that virtually a steady flow condition exists. Flow in the river cannot be considered steady, however. Variations in flow due to hydroelectric operations at Norris Dam may cause 4- or 5-fold variations in the dilution of creek waters at its mouth within a day. An example of variation in flow of the Clinch River from the vicinity of Whiteoak Creek to the mouth of the Emory River during a day is shown in figure 8.

During the period August 14–19, 1961, a test was conducted to determine effects of power releases from Norris Lake on diffusion of radioactive releases from Whiteoak Lake in the Clinch River. Records of Flow at Whiteoak Dam, records of radioactivity (gross beta radioactivity) released from Whiteoak Lake, time of travel from Whiteoak Dam to the mouth of Whiteoak Creek, and variation in flow of the Clinch River (fig. 8) were used in determining variation in concentration of radioactivity in the Clinch River as shown in figure 9.

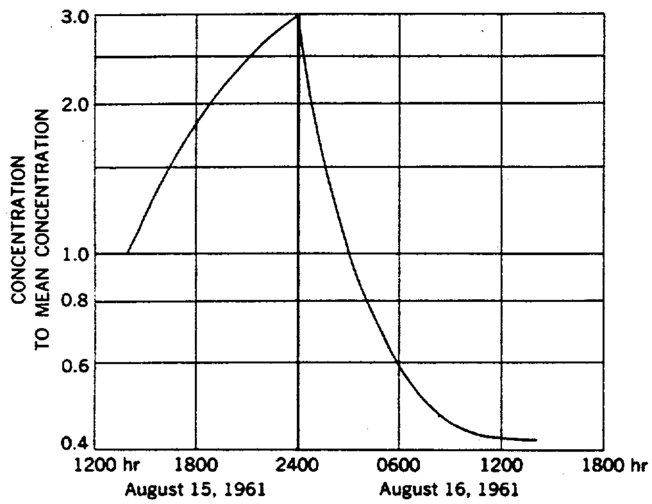

FIGURE 9.—Estimate of variation in concentration of radioactivity in the Clinch River at the mouth of Whiteoak Creek during a 24-hour period, based on records of radioactive releases and of flow in Whiteoak Creek at Whiteoak Dam and of flow in Clinch River at mile 5.5, assuming complete and instantaneous mixing.

Owing to turbulent diffusion, the variations in the concentration of radioactivity of the continuous releases from Whiteoak Creek are attenuated as the waters move downstream in the river from the creek mouth. The effect of this attenuation on the concentration of radioactivity in the Clinch River was observed for 24 hours at a water-sampling station at mile 5.5 (fig. 1), 15.3 miles downstream from the mouth of Whiteoak Creek. Results of these observations of the variation in radioactivity are shown in figure 10. Variations in radioactivity released from Whiteoak Creek on August 15–16, 1961, which were created by effects of power releases (fig. 9), have been completely attenuated through turbulent diffusion.

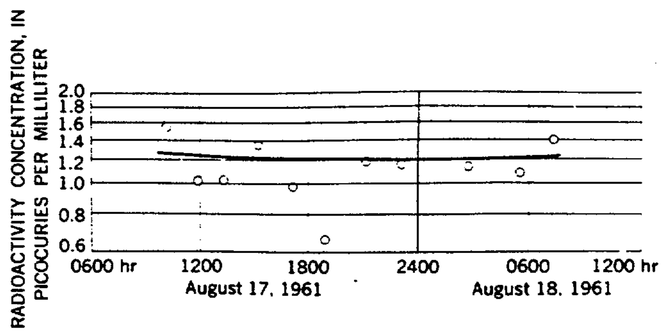

FIGURE 10.—Effects of power releases from Norris Lake on the variation in concentration of radioactivity in the Clinch River at mile 5.5 during a 24-hour period.

For most of the year (years prior to 1962) the variation in dilution within a day is the result of steady flow from Whiteoak Creek and cyclic flow, due to power releases, in the Clinch River. Rapid variations in flow in Whiteoak Creek due to storm runoff do occur and would cause variations in the concentration of radioactivity released to the Clinch River. The concentrations in the radioactive release would vary in a pattern somewhat like that shown in figure 9. Hence, fluctuations in the concentrations of release of radioactivity due to storm runoff from the creek should be effectively damped in a flow distance of 15 miles. The variation in flow during a day in the Clinch River is greatly diminished from that shown in figure 8 if the flow is greater than 10,000 cfs. Releases from Norris Reservoir greater than 10,000 cfs are flood-control releases and are nearly steady. Steady flows in the river would enhance damping due to diffusion.

CONCLUSIONS

The daily dilution factor is a simple measure of dilution afforded by the Clinch River. Flows in the Clinch River dilute radionuclide concentrations of Whiteoak Creek waters 670 times on the average (1951–60). The extreme range in dilution factor is from 4,330 to 5.1. The factor ranges for 10 to 90 percent of the time from 1,400 to 83. A seasonal trend in dilution is apparent, the monthly dilution being less than average from December through May. Minimum dilution factors for durations of 1 to 90 days range from 20 to 302 and 6 to 163 for recurrence intervals of 2 to 10 years.

Two restrictions on indiscriminate application of results of the analyses should be recognized. First, the results are a historic presentation of data rather than a useful predictive tool, because of controlled flow conditions in the Clinch River. Flow in the Clinch River was regulated by Norris Lake until 1962; in May 1962, further regulation of the river occurred after closure of Melton Hill Dam took place. (See fig. 1.) Peak-power releases from Melton Hill Lake will significantly change flow variations and diffusion of low-level radioactive waters in the lower Clinch River from those experienced when regulation was solely by Norris Lake. (See Morton, 1965, p. 108–129.) Second, derivation of daily dilution factors for periods of missing record is not as statistically rigorous as would be desired.

Information in this report is no longer applicable to estimation of short-term variations in dilution because of effects of power releases from Melton Hill Lake on radionuclide transport. The information provides, however, a valuable base for comparative evaluations of these power releases on dilution.

Studies of the kind in this report are useful to waste management. Measures of central tendency (mean or median) indicate whether present means of disposal are adequate. Cumulative frequency curves and magnitude-duration-frequency curves aid in determining storage capacity for temporary holdup of waste. Advantageous times for release of stored wastes may be selected from information on seasonal trends.

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